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MEASUREMENTS OF GAMMA RADIATION OF THE LUNAR SURFACE ON THE SPACE STATION LUNA – 10

by

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S U M M A R Y

This report brings forth the preliminary results of measurements of gamma-radiation of the lunar surface carried out with the aid of a scintillation gamma-spectrometer installed on board of LUNA-10. These measurements covered rather wide areas of the surface, including "continental" as well as "mare" regions on both the visible and far side of the Moon. The energy range of the spectra was from 0.3 to 3.1 Mev, and the integral gamma-emission registered at some 15 points was in the same energy range.

From the comparison of lunar gamma-spectra with the standard (calibration) spectra for various types of rocks it could be concluded that rocks with the same K, Th and U content as in terrestrial acid rocks (of granite type) are absent in the regions of the lunar surface where measurements were taken. This refers, of course, to a layer of about 25 cm depth, for gamma-rays from deeper layers are absorbed in the formation.

Judging from the experimental data on the intensity of gamma-radiation at the expense of natural radioactivity, it may be referred to the level of intensity from basic type rocks (of basalt type). It is not yet possible to exclude the probability that the obtained levels of concentration of natural radioelements were found to be somewhat overrated.

It is interesting to note in connection with the above that tektites, as bodies close in their composition (& U, Th and K content) to acid rocks, evidently cannot have a lunar origin, an assumption made quite often.

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Author

STATEMENT OF THE EXPERIMENT

The space station LUNA-10 was brought into a selenocentrical orbit on 3 April 1966. Installed on board was a 32-channel scintillation gamma-spectrometer designed for the investigation of the intensity and of the spectral composition of gamma-emission from the lunar surface. The investigation of the latter's radioactivity is of interest from many viewpoints.

* IZMERENIYA GAMMA-IZLUCHENIYA LUNNOY POVERKHNOSTI NA KOSMICHESKOY STANTSII LUNA-10

First of all, it allows an experimental approach to the solution of the question of lunar surface's chemical composition, question closely linked with the origin and the evolution of the Moon and of solar system's planets as a whole, and also more particularly with the problems of geochemical processes taking place inside the planets in the course of their evolution.

Secondly, inasmuch as the Moon is constantly subject to acting irradiation by cosmic rays, induced radioactivity should be expected on it, analogous to that found in meteorites fallen on Earth. The investigation of such a radioactivity allows to draw a series of conclusions in regard to the intensity and energetic composition of cosmic rays near the Moon, and also on the effects induced by radiation generated during solar flares, etc.

Finally, the study of the intensity and of spectral composition of Moon's gamma-radiation provides information relative to radiational environment on its surface.

The investigations described in the present work constitute the first attempt to detect the gamma-radiation of the Moon and to determine its spectral composition. No such type of measurements have been conducted to-date.

The absence on the Moon of sufficiently dense atmosphere absorbing gamma-radiation allows to perform its registration directly from the satellite orbit. The certain counting rate decrease taking place during these measurements is due to the decrease of the solid angle at which the surface of the Moon is seen (instead of a solid angle 2π, we found for the initial orbit in periselion an angle of about 0.9π and in the aposelion 0.46π).

Similarly to what is observed on Earth, the gamma-emission of the lunar surface must be linked with the presence in lunar rocks of natural radioactive elements, that is, thorium and uranium with their products of decay, and also of the natural radioactive isotope of potassium K^{40}.

Methods are worked-out at present for determining the potassium, thorium and uranium content with the aid of a gamma-spectrometer. When setting up the experiment it was assumed that the gamma-spectrometer installed on the Moon's artificial satellite (ASM) will allow to detect potassium, thorium and uranium by the gamma-radiation and to determine their relative content in lunar rocks.

It is well known from the analysis of various types of terrestrial rocks that: a) the highest content of each of the radioactive elements is observed in acid rocks (granites and others), broadly distributed over continents; b) the concentration of radioactive elements decreases with regularity when passing from acid to basic rocks and further to the ultrabasic, whereupon this decrease encompasses a range of several orders of magnitude.

On the basis of knowledge of K, Th and U concentration in the rock one may, in principle, estimate the type of the rock and, consequently, its composition too. To-date there has been no information on the composition of lunar surface's rocks.

When setting up the experiment it was taken into account that the level of gamma-radiation from natural radioactive elements may result notably below the level of gamma-radiation occurring at interaction of primary cosmic particles, namely protons, with the lunar matter. The nuclear reactions then taking place are attended by a characteristic gamma-emission. The spectral distribution of gamma-quanta has a complex character and is dependent on both the energy of incident particles and on the chemical composition of the irradiated matter. This question is treated and clarified at further length in the work [1]. Because of shieding by the atmosphere such an effect is practically absent on Earth. For the Moon the investigation of the induced radioactivity offers a particular interest, inasmuch as its surface is the object of constant action by primary cosmic radiation.

The scintillation gamma-spectrometer installed aboard LUNA-10 included a gamma-ray detector, consisting of a cylindrical NaI (Tl) crystal of 30 x 40 mm transverse dimension, conjugated with an FEU-16 photomultiplier and a pulse amplitude analyzer. The device allowed the measurement of gamma-emission spectra at the background of charged particles. To that effect the fundamental crystal NaI (Tl) was in a container of thin plastic scintillator.

With the aid of such a laminar (stratified) scintillator the pulses from charged particles registered in both crystals, passing through the corresponding transmitter scheme, separated from the pulses induced by gamma-quanta which failed to be registered by such a plastic scintillator.

The device registered gamma emission spectra in two energy ranges, from 0.3 to 3.1 and from 0.15 to 1.5 Mev. The band change-over was achieved by special command aboard the station. The pickup and analyzer of the spectrometer were located inside the station's hermetic compartment under a shield of about 1 g/cm^2 thickness.

Only part of the material obtained from LUNA-10 has been processed to date. Described below are the preliminary results of processing of gamma-spectra obtained in the lunar orbit and also over the flight trajectory Earth-Moon.

RESULTS OF THE EXPERIMENT

During the first month of operation 6 gamma-emission spectra were obtained by LUNA-10 in the energy range 0.3 – 3.1 Mev. Moreover, the integral intensity of gamma-radiation was measured at 15 points in the same energy range. The measurements encompassed rather broad areas of the surface, including "continental" and "mare" regions on the visible as well as on the far side of the Moon. The height above the surface and the approximate selenographic coordinates of the region above which measurements of spectra were conducted are compiled in Table 1.

TABLE 1

Height above the Surface and Selenographic Coordinates of the Regions of Measurements

Spectrum No.	Date and Time of Measurements		Aver. altitude above the surf. km	Selenographic latitude, deg		Selenograph. long., deg.	
				beg.	end	beg.	end
1	5 April	19 26 hrs	350	+70	+62	185	228
2	5	20 11	600	–22	–40	272	279
3	8	04 45	700	–47	–63	253	273
4	9	01 37	600	–63	–64	252	272
5	18	12 41	600	+30	+52	291	305
6	21	13 56	1000	–58	–45	208	220

Fig. 1 illustrates one of the primary gamma-spectra (curve 1) obtained when LUNA-10 was in orbit around the Moon. This spectrum was measured on 8 April 1966 at 04 00 hours over the far side of the Moon (spectrum No.3). Shown here also is the spectrum of the background (curve 2) caused by the interaction of cosmic rays with the substance of the probe (taking into ac-

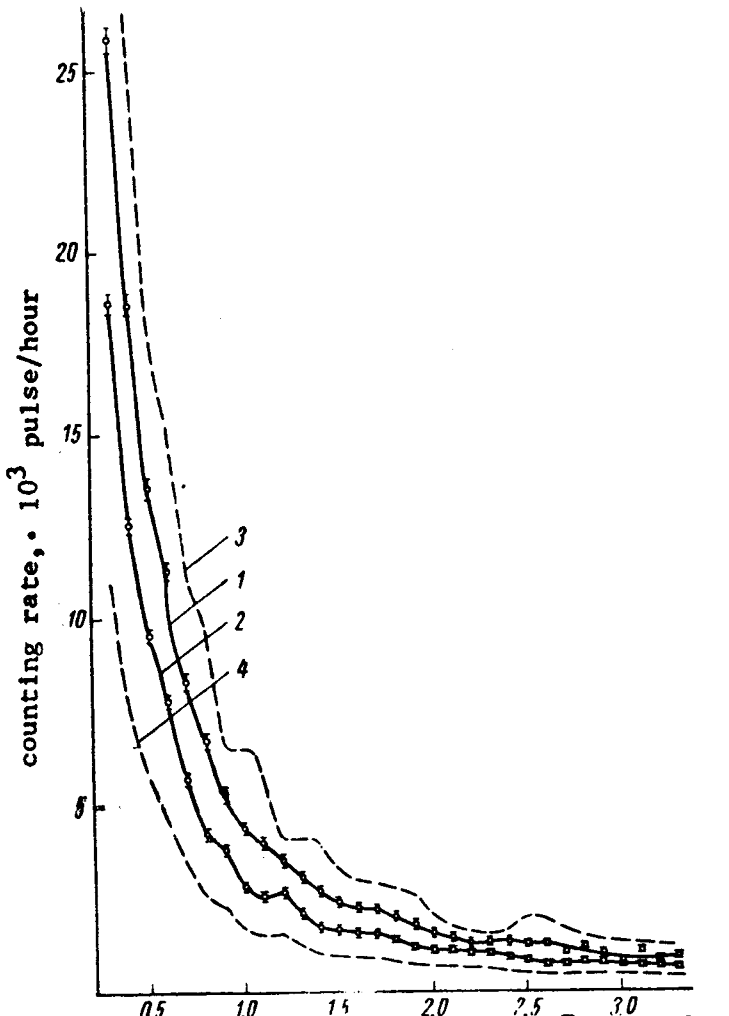

Fig. 1

Gamma-emission spectra obtained in the orbit of AMS*
and over the flight trajectory EARTH — MOON

1. Gamma-emission spectrum of lunar rocks with background;
2. Gamma-spectrum of the background due to interaction of cosmic rays with the substance of the station and with correction for shielding by the Moon;
3. & 4. Same spectra (respectively curves 1 and 2), converted for the case of measurements on the Moon's surface. The errors shown in the drawing are root-mean-square errors.

count the shielding by the Moon).

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* AMS stands for "artificial Moon's satellite.

Compared with the counting rate of gamma-quanta measured over the flight trajectory, the counting rate in the orbit around the Moon increases by 30–40 %. Because of the shielding action of the Moon, the background resulting from the probe's irradiation by cosmic particles near the Moon decreases, and con-

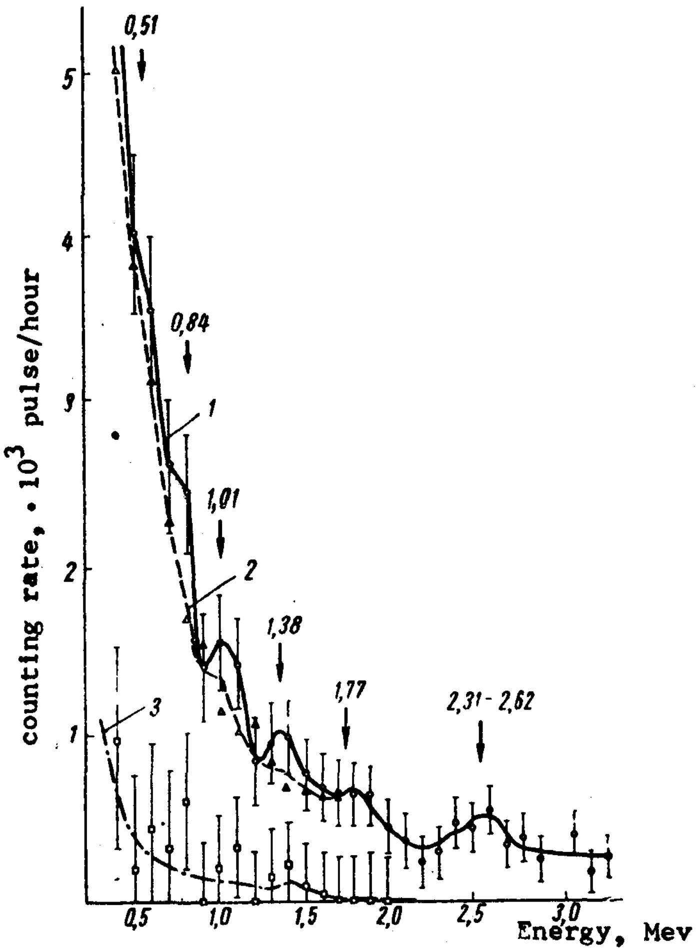

Fig.2. Gamma-emission spectra of lunar rocks obtained in AMS orbit

1. Gamma-emission spectrum of lunar rocks after subtracting the background;
2. Gamma-emission spectrum connected with the processes of cosmic ray interaction with lunar rocks (instantaneous gamma-radiation and decay of cosmogenous isotopes);
3. Spectrum of gamma-radiation linked with decay of natural radioactive elements K, Th and U, included in the lunar rocks.

tains from 78 to 89 percent of the background over the flight trajectory. Therefore, during measurements in orbit of the ratio of Moon to station's background effect, we obtained in our measurements about 0.6.

The background spectrum was measured during the flight of LUNA-10 at a distance of about 230,000 km from the Earth. The main part of the registered background gamma-radiation is linked with inelastic interaction processes of charged particles with the substance of the probe, and is not the primary cosmic radiation. The probe's inherent radioactivity on account of the presence in its substance of K, Th and U was small. Radioactive sources were absent aboard the probe.

Figure 1 shows also the curves related to the case, whereby the measurements would be conducted directly on the Moon's surface. Curve 3 provides the gamma-spectrum on the Moon's surface together with the probe's irradiation background; the curve 4 indicates the background. The increase of Moon'effect ratio to station background to the value of 3.2 takes place on account of the increase of the solid angle, at which the surface of the Moon is seen and because of background effect decrease on account of greater shielding from cosmic radiation.

Plotted in Fig. 2 (curve 1) is the gamma-emission spectrum of lunar rocks (upon deduction of background) for the height at which the station (probe) was at the time of measurement. This curve is the difference between the spectra shown in Fig.1.

As may be seen from Fig. 2, the lunar gamma-spectrum differs essentially from that on the surface of the Earth, of which the shape is basically determined by the content in natural radioactive elements in the investigated rock. A distinctive peculiarity of the lunar gamma-spectrum is the relatively gradual drop and the presence of a large number of hard gamma-quanta with energy greater than 1.5 Mev, whereas for the spectrum of natural radioelements, a steep drop is characteristic of energy increase and of absence of gamma-quanta with energy greater than 2.62 Mev.

If in the gamma-spectrum on the surface of the Earth there are about 5 % of gamma-quanta with energies higher than 1.5 Mev (measurements being made with the aid of the given device), there are about 20 percent of them in the lunar gamma-spectrum. It may be concluded from these data that the nature of the main part of gamma-radiation arriving from the Moon's surface is connected not with the natural radioactivity of U, Th and K^{40}, but is the consequence of continuous interaction processes of cosmic rays with lunar matter and of cosmogenous isotope decay.

During collisions of primary particles with the nuclei of the target, free nucleons are formed according to the type- (p, xpn) reaction, which form in their turn by interaction with other nuclei, nucleonic cascades. The residual nuclei may be in a state of excitation, the transition from which into ground state is attended by gamma-quantum emission. The energies of emitted gamma-quanta depend for every isotope on the scheme of its energy levels, i. e. the radiation is characteristic.

Table 2 shows the energies of gamma-rays identified in the lunar gamma-spectrum. Indicated here also are the basic nuclear reactions on the probable rock-forming elements of the lunar rocks, as a result of which gamma-rays of given energies are emitted.

It may be seen from Table 2 that the reactions with O, Si, Al and Mg, i. e. with those elements of which the dissemination is presumed to be greatest, proceed with optimum yield.

TABLE 2

Energy Mev	Basic nuclear reactions leading to the emission of gamma-quanta of given energy
0,84	$Al^{27}(p,p'\gamma)Al^{27}$, $Si^{28}(p,2p\gamma)Al^{27}$, $Fe^{56}(p,p'\gamma)Fe^{56}$
1,01	$Al^{27}\ p,pn\gamma)Al^{26}$, $Si^{28}(p,2pn\gamma)Al^{26}$
1,37	$Mg^{24}(p,p'\gamma)Mg^{24}$, $Al^{27}(p,pt\gamma)Mg^{24}$, $Si^{28}(p,p\alpha\gamma)Mg^{24}$
1,78	$Mg^{24}(p,p\alpha\gamma)Ne^{20}$, $Al^{27}\ p,2p\gamma)Mg^{26}$, $Si^{28}(p,p'\gamma)Si^{28}$
2,31 } 2,62 }	$O^{16}(p,2pn\gamma)N^{14}$, $Mg^{24}(p,pn\gamma)Mg^{23}$, $Mg^{24}(p,2p\gamma)Na^{23}$, $Al^{27}(p,ptn\gamma)Mg^{23}$

Some of the daughter-nuclei having formed as a result of nuclear reactions are radioactive and may emit gamma-quanta at decay. These so-called cosmogenous radioisotopes are detected, for example, during the study of the radioactivity of meteorites having fallen on the ground. Inasmuch as the lunar surface is constantly subject to tha action of cosmic rays, all the cosmogenous radioisotopes must be in radioactive equilibrium. This is why long-lived and short-lived radioisotopes will be present among the various emitters in the amounts proportional to their effective formation cross-section.

Calculations show that the main contribution is provided by the decay of the following cosmogenous isotopes:

O^{14} ($T_{1/2}$ = 72 sec., E_γ = 2.31 Mev), O^{19} ($T_{1/2}$ = 27 sec, E_γ = 1.37 Mev), F^{20} ($T_{1/2}$ = 10.7 sec, E_γ = 1.63 Mev), Na^{22} ($T_{1/2}$ = 2.6 years, E_γ = 1.28 Mev), Na^{24} ($T_{1/2}$ = 15 hrs, E_γ = 1.37 and 2.76 Mev).

These radioisotopes are formed with notable yields at nuclear interactions with the same basic rock-forming elements O, Mg, Al and Si. The cosmogenous radioisotopes with higher mass-number A are actually formed only at nuclear interactions with iron.

Alongside with nuclear reactions leading to typical gamma-ray emission (instantaneous gamma-radiation and cosmogenous radioisotope decay), a certain contribution is made by π^0-meson decay processes and by proton and electron bremmstrahlung. The spectra of the latter two processes have a continuous character. Because of this the overall spectrum of Moon's gamma-emission is blurred, or washed out, and becomes less prominent.

The peak of 0.51 Mev is the peak of annihilation radiation. This peak is particularly clearly evident during measurements of lunar spectrum in the energy range from 0.15 to 1.5 Mev.

We have shown in our work [1] the possibility, in principle, to estimate the chemical composition and the type of a rock by cosmic-ray induced gamma-radiation. At present attempts are made to obtain from the Moon's gamma-emission spectra transmitted by Luna-10 the data relative to content in O, Si, Al and Mg of rocks above which measurements were conducted.

Analysis of the results of measurements attests to the fact that the intensity of gamma-radiation over various regions of the Moon's surface, after correction for measurement height, was practically constant (the variation between the measurements did not exceed 40%). Obviously, this result is also explained by the fact that the main source of gamma-rays is the irradiation by cosmic particles, factor acting practically identically over the entire surface.

According to preliminary data from the processing of gamma-spectra, the overall dose of gamma-radiation on the lunar surface somewhat exceeds the rate of the dose above the rocks of the earth's crust. Compared with terrestrial granite (14 microroentgen/hour), the rate of the dose from gamma-rays on the Moon's surface is 1.5 – 2 times higher (in rough estimate).

The characteristics of the Moon's gamma-spectrum render extremely difficult the evaluation of the level of gamma-radiation. The estimate of the level of natural activity and the determination of the concentration of natural radioelements may be made if we subtract from the obtained lunar gamma-spectrum the effect of gamma-radiation conditioned by interaction of cosmic rays with lunar rocks. Unfortunately the exact shape of the spectrum of gamma-rays obtained here and resulting from cosmic ray effects, is not known.

We have taken in the first approximation the shape of the spectrum obtained over the trajectory Earth-Moon, inasmuch as its nature is linked with the same processes. Curve 2 of Fig.2 is the spectrum of gamma-radiation of lunar rocks governed by cosmic rays. This curve was obtained by superimposition in the energy region above 2 Mev (the contribution from natural radioisotopes being practically absent) of the spectrum obtained over the Earth-Moon trajectory with the spectrum of gamma-radiation of lunar rocks. At such a construction we allowed for one admission, assuming that gamma-spectra induced cosmic rays in the substance of the station and in lunar rocks are identical in shape and different only in intensity. The validity of this admission is based upon the fact that the station's frame, as well as a substantial part of the on-board apparatus, are manufactured from light alloys, which means that the same chemical elements enter in their composition as those being fundamental rock-forming elements (Si, Al, Mg, and little of Fe). Practically the same gamma-emitters are formed on these elements with optimum yields, whereas the variations in their relative content change little the shape of the spectrum (particularly of such a little prominent spectrum as that obtained from LUNA-10). This found confirmation in our theoretical calculations and in model-experiments on an accelerator.

Curve 3 of Fig. 2 constitutes the difference between the curves 1 and 2. Provided the above is correct, this part of gamma-radiation may be regarded as due to decay of natural radioactive elements.

As may be seen from the spectra brought out in Fig.2, 90 percent of total intensity of gamma-radiation of lunar rocks is constituted by radioactivity induced by cosmic rays, with no more than 10 percent due to K, Th and U decay.

The gamma-spectrometer designed to investigate the Moon's gamma-radiation was first calibrated under terrestrial conditions, using standard samples with known content in K, Th and U, as well as utilizing rock samples with various contents of these elements. On the basis of these data it was possible to compute gamma-spectra that should emerge during measurements in the orbit of AMS for rocks with varying contents of natural radioactive elements (in the absence of cosmic-ray induced radiation).

Fig. 3 shows such spectra for measurements at 350 km (the background being subtracted). The cross-hatched areas correspond to the range of concentrations of radioactive elements for the given type of rock. The average values of Th and U concentrations, borrowed from the work [2] by Vinogradov, were used for the construction of spectra; they are plotted in Fig. 3.

From the comparison of Moon's gamma-spectra with standard rocks of various types it follows that rocks with identical K, Th and U contents as in the acid terrestrial rocks (of granite type) are absent at least in three regions of the Moon's surface over which measurements were conducted. It should be noted at the same time, that reference is made here to the surface layer of approximately 25 cm depth. Gamma-rays from deeper layers are absorbed in the rock.

The experimental data on the intensity of gamma-radiation due to natural radioactivity (Fig. 2, Curve 3) allow us to ascribe it to the level of intensity obtained from rocks of basic composition (basalt type). However, it is presently still impossible to exclude the probability that the observed level of concentrations of natural radioelements is somewhat overrated.

It is interesting to note in this connection that by their composition (and U, Th and K content), tektites are close to terrestrial acid rocks. As such they obviously can not have a lunar origin as was often assumed.

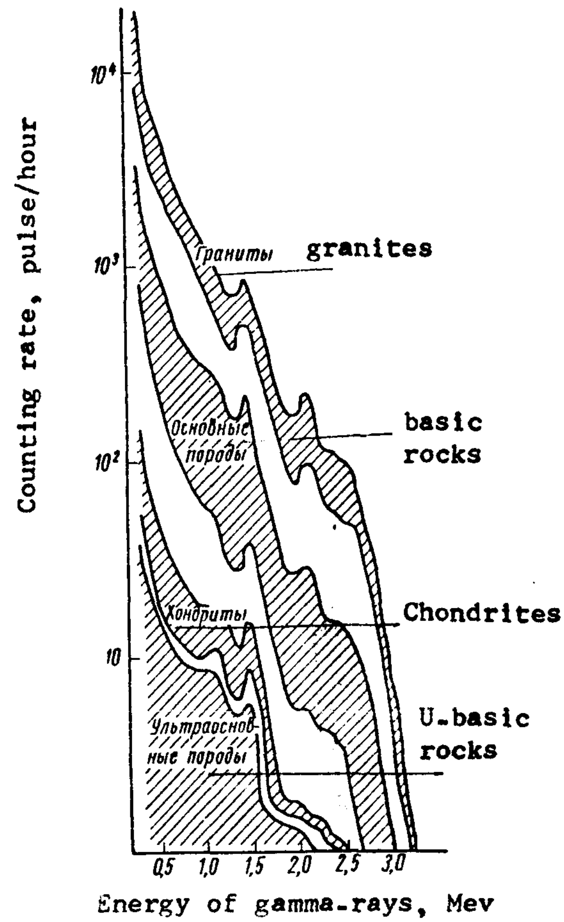

Fig.3. Gamma-ray spectra of lunar rocks, which must be obtained in the AMS orbit from the gamma-radiation of natural radioactive elements for relative K, Th and U contents, corresponding to the contents of the principal types of terrestrial rocks

C O N C L U S I O N S

Experimental research on the intensity of and spectral composition of gamma-radiation of lunar rocks, conducted with the help of a gamma-spectrometer installed on board of the automatic station LUNA-10, has shown the following.

1. The general level of gamma-radiation of lunar rocks approaches the level of gamma-radiation over the rocks of the terrestrial crust, somewhat exceeding it. According to a preliminary estimate, the intensity of gamma-radiation of lunar surface surface (for regions of measurements) constitutes 20 to 30 micro-roentgen/hour.

2. The main contribution of lunar gamma-radiation is made by interaction processes of cosmic rays with the lunar matter (instantaneous gamma-radiation of cosmogenous isotope decay). About 90 percent of the total gamma-radiation of the Moon may be ascribed to these processes.

3. Analysis allowed us to identify on the lunar spectrum the photo-peaks of gamma-quanta emitted during the interaction of cosmic particles with the basic rock-forming elements of the lunar surface: O, Mg, Al, Si, as well as the gamma-quanta emitted during cosmic isotope decay. (The possibility of determining the relative content of these elements by means of interaction spectrum with cosmic rays is now being studied).

4. The results of measurements over various regions of the lunar surface including those of "continents" and "maria" did not permit us to reveal a noticeable level difference in the intensity of gamma-radiation over these regions (differences not exceeding 40 percent).

5. The share of gamma-radiation of lunar rocks due to K, Th and U decay is no higher than 10 percent of the total gamma-emission of lunar rocks.

6. Comparison of the intensity of gamma-radiation due to decay of natural radioactive elements K, Th and U with the results of calibration of the device on ter estrial formations allows to ascribe to lunar rocks elements of radiations of radioactive elements close to those of terrestrial basic rocks (of the basalt type).

TABLE 3

RELATIVE K, TH AND U CONTENT IN THE PRINCIPAL TYPES OF TERRESTRIAL ROCKS AND STONE METEORITES
(weight, %)

Elements	Acid rocks (granites etc.)	Intermed. (diorite, andesites)	Basic rocks (Basalts etc.)	"Primitive" basalts	Stone-meteorites chondrites	Ultrabasic rocks (peridotites, lunar & oth)
K	3,34	2,3	0,83	0,1	0,085	0,03
Th	$1,8\cdot10^{-3}$	$7\cdot10^{-4}$	$3\cdot10^{-4}$	$4\cdot10^{-5}$	$4\cdot10^{-6}$	$5\cdot10^{-7}$
U	$3,5\cdot10^{-4}$	$1,8\cdot10^{-4}$	$5\cdot10^{-5}$	$1\cdot10^{-5}$	$1,5\cdot10^{-6}$	$3\cdot10^{-7}$

The data obtained allow us to exclude for the regions of the lunar surface where measurements were conducted, the existence of rocks with the same radioactive element content (K, Th and U) as in terrestrial acid rocks (granites and others), and, a fortiori of rocks with ore concentrations of these elements.

At the same time, it is not now possible to exclude the possibility of existence in these regions of the lunar surface of ultrabasic meteoritic matter.

THE END

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on 24 June 1966

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20 - 26 September 1966

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400	BOURDEAU	
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610	MEREDITH	
611	McDONALD	(6)
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613	KUPPERIAN	(6)
614	WHITE	(4)
615	BAUER	(4)
640	HESS	(3)
	O'KEEFE	(3)
641	CAMERON	
	BURLEY	
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	FRENCH	
620	SPENCER	
630	GI for SS	(3)
252	LIBRARY	
256	FREAS	

N A S A H Q S

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